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Fig.1.

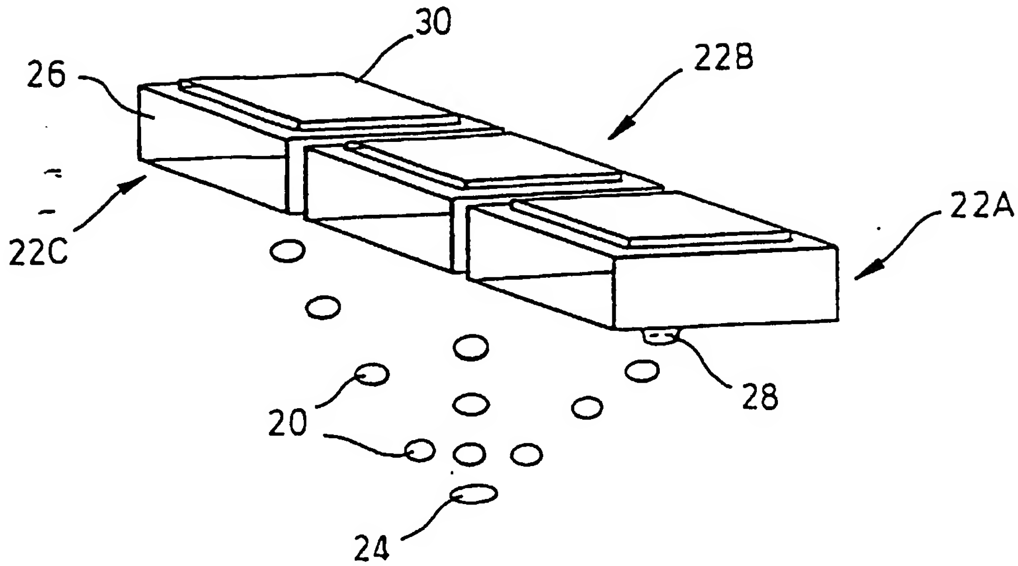


Fig.2.

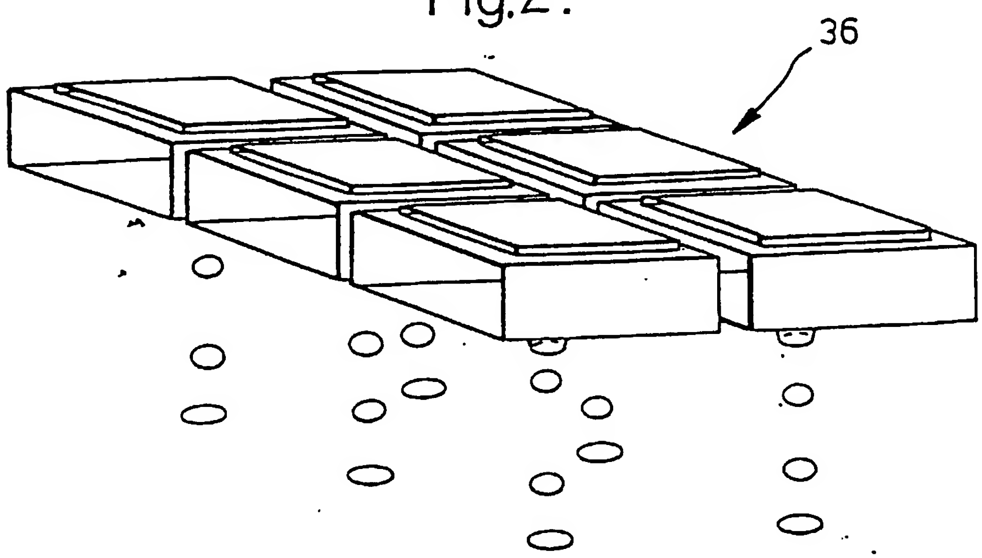
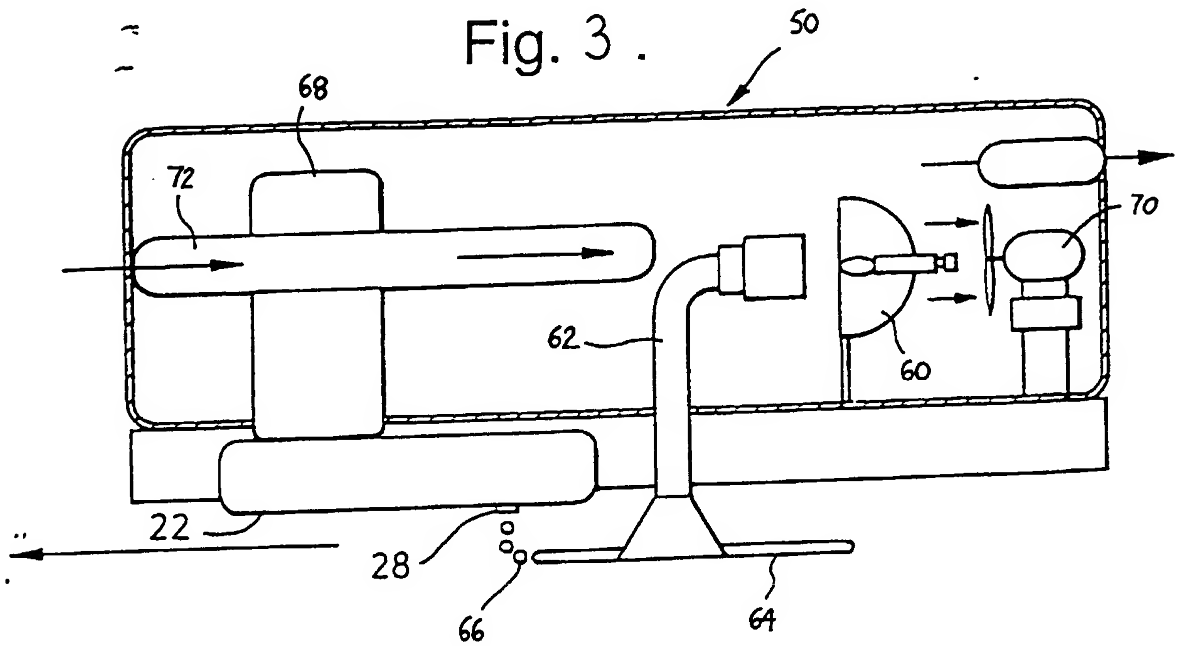


Fig. 3 .



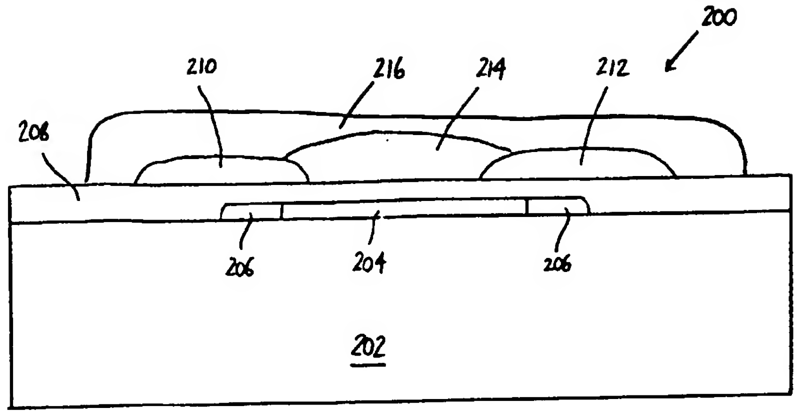


FIGURE 4a

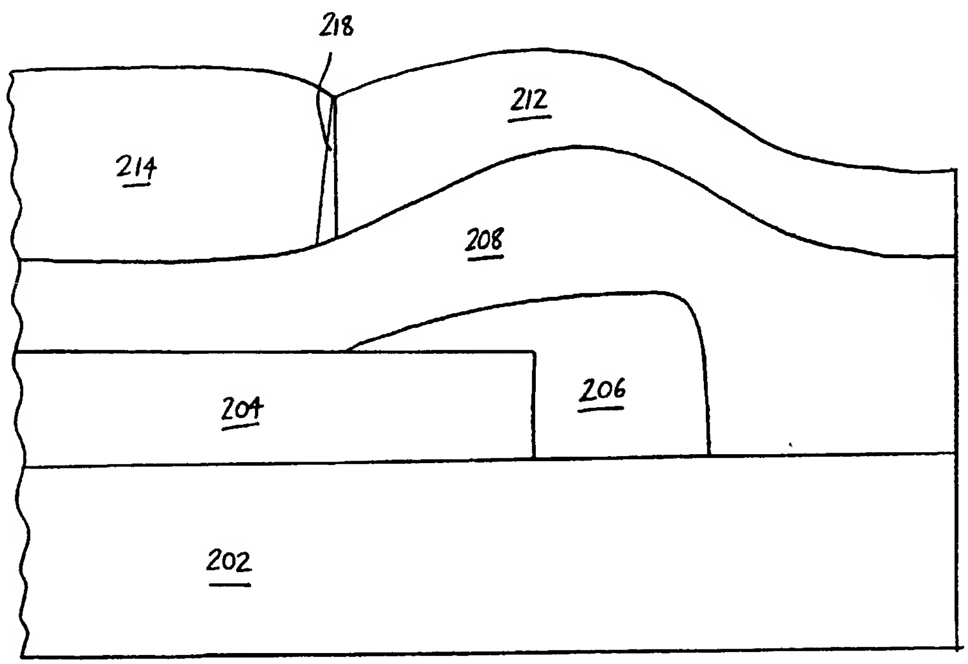


FIGURE 4b

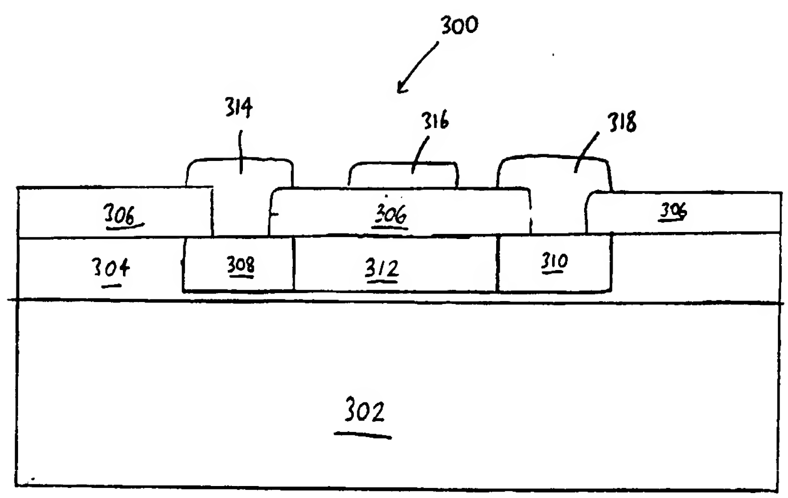


FIGURE 5

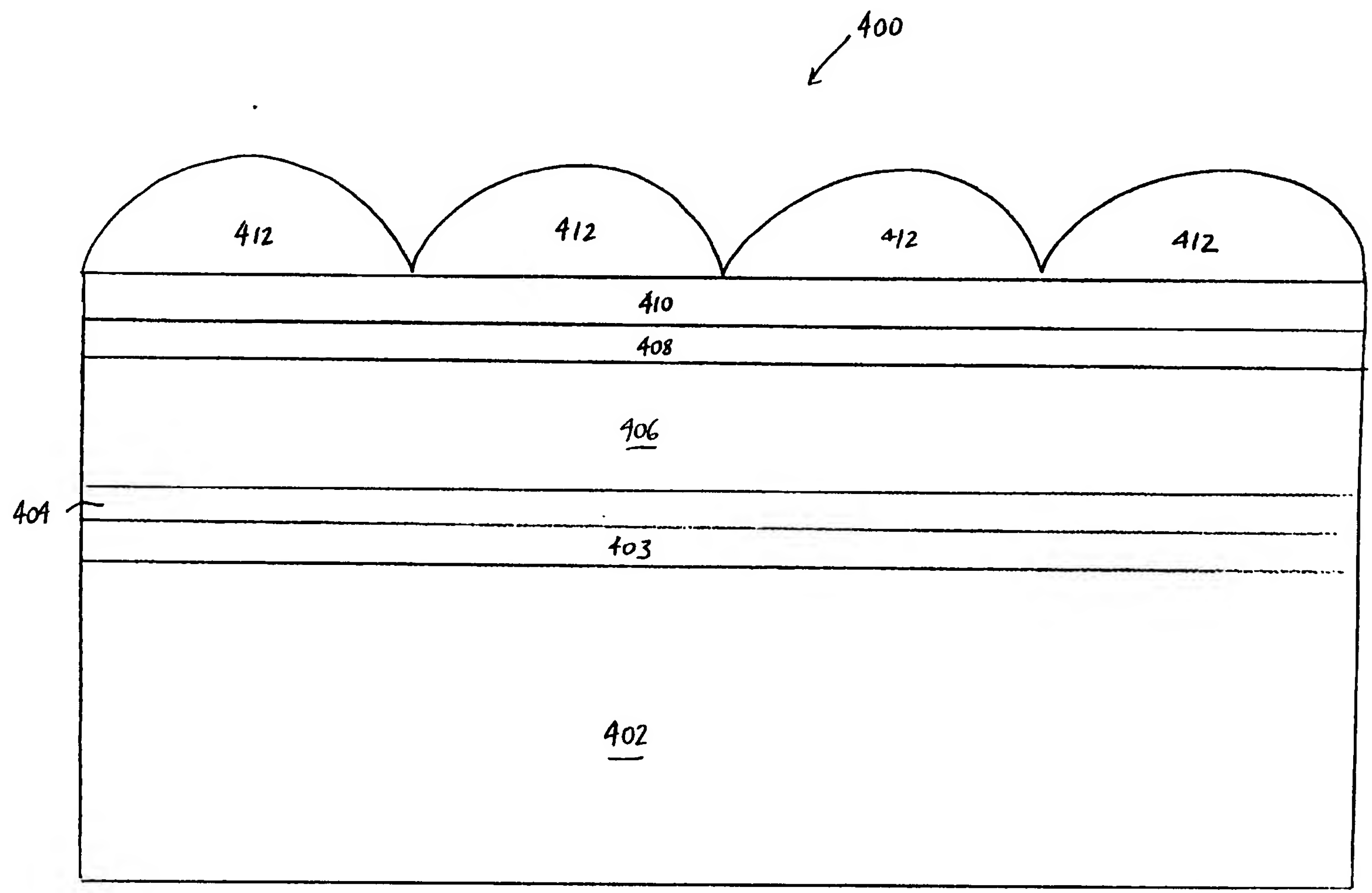


FIGURE 6

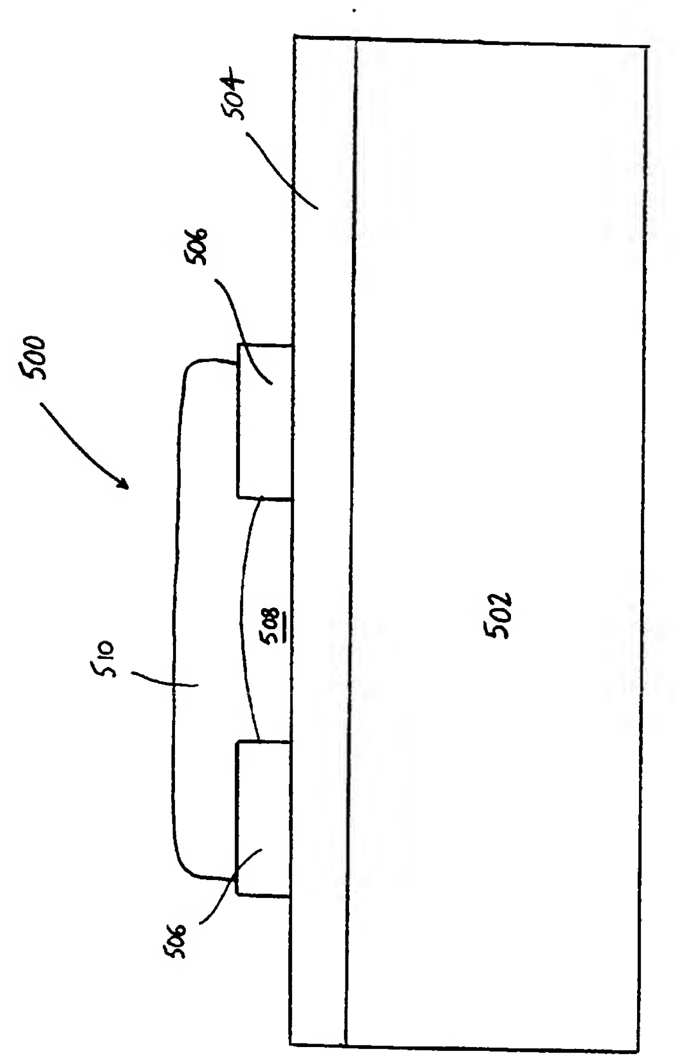


FIGURE 7

METHOD OF FORMING AN ELECTRONIC DEVICE

The present invention relates to a method of forming an electronic device. In particular, the present invention relates to a method of forming an electronic display device.

Semiconductor devices, and in particular integrated circuits, are the basic elements of electronic circuits. Integrated circuits typically consist of a number of discrete layers, formed from insulating, semiconductor or electrically conducting material, formed on a semiconductor substrate. These layers can form part of a component of the integrated circuit, such as a transistor, an interconnection between components, or provide an isolation barrier between components.

The fabrication of devices involves a number of different processes for forming the layers which make up the device. Such processes include:

- photolithography;
- vacuum deposition;
- chemical vapour deposition;
- oxidation;
- etching;
- masking; and
- dopant diffusion.

The number of processes required to manufacture, for example, a field effect transistor makes the manufacturing process slow. In addition, the use of processes such as etching and dopant diffusion which are difficult to accurately control can lead to loss in accuracy in the shape and performance of the finished product.

Drop-on-demand printing is a known printing technique whereby a droplet of ink is ejected from a ink-jet printhead. The droplet impacts with a porous or semi-porous surface, dries and forms a spot which forms a recognisable pattern and colour such as type.

The present invention provides a method of forming at least part of an el ctronic display d vice using the technique of drop on d mand printing to deposit droplets of deposition mat rial, said method comprising depositing a

plurality of droplets of fluid comprising soluble or dispersed phophor and/or dye on a selective area of a partially formed display device, and curing the deposited fluid by exposing the deposited fluid to electromagnetic radiation.

The present invention relates to the deposition of soluble or dispersed phosphors and dyes contained in a suitable fluid medium for the purpose of providing a selective area deposition of the said phosphor for device applications.

An example is the use of this technique for field emission flat panel displays in which it is necessary to have a phosphor layer that emits photons when impacted by energised electrons. The deposition technique can be employed to provide one or more phosphor layers adjacent to an imaging pixel on a typically glass cover that houses the transparent top contact.

The dyes and/or phosphors can be deposited in 3-D as required, with the height variation being selective over the deposition surface. Typical deposition materials include ferrous chelates, silicophosphates, ormocers, etc.

The present invention can makes use of a printhead to deposit droplets of an array of custom fluids that when suitably dried on a surface form all of the elements necessary for, for example, a planar flat panel display.

The volume of each droplet is typically between 1 picolitre and 1 microlitre. This enables the final shape of a device to be accurately controlled during the formation thereof, and enables a wide variety of different shapes of devices to be formed.

Display types include, but are not limited to:

- polymeric and/or organic electroluminescent displays;
- field emission displays;
- electrochromic displays;
- photochromic displays;
- liquid crystal displays; and
- ferroelectric displays.

The application of the invention is wide. For instance, directly deposited full colour, high resolution displays can be fabricated on selected areas of a planar or three-dimensional irregular surface. The surface can be rigid or flexible, and can be conductive, semiconductive or insulating.

The present invention also provides a means of forming a non-intrusive, transparent displayed information on a screen that can be used in all aspects of life, including, but not restricted to, helmet visors, opthalmic and protective glasses, sunglasses, car windscreens, aircraft windscreens and observation portals, mirrors, and displays initiated when emergency arises to provide an escape route and emergency procedure data. This invention enables the cheap deposition of displays onto a wide variety of products to facilitate access to IT messages and other information.

Preferably, the display comprises at least one electrically active display pixel, at least two adjoining portions of the or each pixel being formed from one or more different deposition materials.

Printing materials include, but are not restricted to:

- conjugated polymers (eg, MEH poly(phenylene vinylene);
- polythiophene; and
- polyacetyllene derivative.

The method may further comprise the step of depositing an anti-reflection coating over said display device.

The anti-reflection coating may incorporate at least one of scratch resistance, water permeation and dielectric isolation. The coating may be formed from an ormocer, such, as for example, a siloxane.

The method may employ at least one printhead attached to a robotic arm to deposit said droplets. By using a robotic arm having a high degree of freedom, a planar flat panel display may be deposited on a wide variety of flat and three-dimensional surfaces, such as curved windscreens on automobiles.

A lenslet array or a lenticular lens structure may be deposited on surface of the display to provide thre -dimensional display effects.

An electrostatic spray head may be used to d posit said deposition material.

The present invention will now be described by way of illustration only and with reference to the accompanying Figures in which:

Figure 1 shows three deposition heads directed towards a coincident drop site on a print surface;

Figure 2 shows an array of deposition heads;

Figure 3 shows a cross-sectional view of a deposition head in combination with a UV light source;

Figures 4a and 4b are cross-sectional views of a transistor;

Figure 5 shows a cross-section of a chemotransistor;

Figure 6 shows a cross-section of a solar cell; and

Figure 7 shows a cross-section of a display pixel.

Referring to Figure 1 a three-dimensional electronic circuit element is formed on a printing surface using a drop-on-demand deposition technique to drop multiple droplets 20 of a deposition material from a number of deposition heads 22A, 22B, 22C. The deposition heads have a height above the printing surface between 5µm and 1000µm. Each deposition head 22A, 22B, 22C holds the deposition material and ejects it a droplet at a time on demand onto the print surface. The deposition materials comprises in excess of 40% solid matter and may be any one of the materials discussed in the introduction.

Each deposition head comprises a pressure generation cavity 26 with a profiled cylindrical nozzle 28 in one wall of the cavity and a PZT bimorph actuator 30 in an opposite wall. Each nozzle 28 defines a line of ejection which is representative of the path a droplet of deposition material will take upon ejection.

Figure 1 shows thre deposition heads directed towards a single drop site, although any suitable numb r of deposition heads may be used to form the desired circuit element. Of course, each deposition head may be directed towards respective drop sites rather like a conventional printer head, as shown in Figure 2. Such a two-dimensional array 36 may provide for the simultaneous deposition of multiple droplets.

Figure 3 shows a deposition head 22 as part of a X-Y deposition system 50. The system 50 includes a quartz-halogen lamp 60 supplying UV light through an optical fibre 62 to the printing surface 64 onto which the droplets 66 are deposited. This system 50 subjects the deposition material to radiation treatment after it has been deposited for the purposes of curing the material or other processing.

The system 50 employs digital deposition servo drive motors for x-axis and y-axis transport motion. A replaceable polymer deposition head 22, along with its associated polymer reservoir cartridge(s) 68, resides on the axis drive carriage plate. Integrated into the carriage plate is a set of annular fibres that permit close proximity UV and infrared radiation for surface pre-treatment, in-flight treatment and/or post deposition treatment. The annular radiation emitters are fed from a fibre optic 62 that is coupled at the opposite end to the light source 60. The deposition surface 64 may be electrostatically secured to the deposition frame. The use of a cooling fan 70 and cooling air directional ducting 72 maintains the system 50 at a working temperature.

The characteristics of the element to be produced are drawn on a computer screen using a suitable draw facility software package or are imported into the plotter drive computer memory using a digital scanning facility (with on board character recognition capability, as required). The finished map is digitised and the appropriate x-y co-ordinates are fed to the system interface so that the required element is formed at the location requested. The drive waveform to the droplet dispense pressure generator (polymer dispense head) is synchronised to the x-y placement co-ordinates, so that the required element is accurately placed. For specific surfaces it is possible to employ an adhesion enhancing liquid pr -treatment prior to depositing th required polymeric pattern.

Int gral continuous or pulsed UV (also in conjunction with infrared radiation - thermally assist d curing) light source with illumination of the dispensing droplet via a fibre-optically fed focusing annulus may be located in close proximity to the dispensing head (or nozzle array). Note that in the limit (high value or high polymer dispense volume applications) this light source could be an excimer laser that employs a rotating mirror arrangement to create a fine line UV light beam that is continuously rotating around a selectable circular radius or more complex elliptical shape. The annulus can be formed by using a suitable retaining mould in the Y-spider plate, and with the use of a pre-shaped top casting cap, PMMA or alternative polymer can be injected into the unit for a UV transmitting annulus with a particular optical focusing. It is envisaged that a suitable light source can be manufactured that would enable the annulus to be fed from a source that is also integrated onto the y-axis carriage plate.

The shape and surface of the nozzle 28 determines the energy needed to eject the droplet from the nozzle. A polished nozzle 28 will have a lower surface energy than an unpolished nozzle and therefore will more easily release a droplet. A low surface energy nozzle exit can be achieved using a variety of liquid coatings (i.e Montedison Galydene), however a more practical route is to gravure print a silicone loaded acrylic UV curing film on to the front of the nozzle plate (this exhibits a surface energy of less than or equal to 19 dyn cm (190μjoules)). One advantage of using such coating materials is that the nozzle can be made of both copper (wetting) and laminate material (wetting or non-wetting) giving more flexible control over the direction of droplet ejection. Both materials can be obtained in a variety of metal and laminate core thicknesses.

The nozzle may incorporate an integral piezoelectric bimorph nozzle shutter (not shown) to act as a sealant for the deposition material retained in the nozzle. This feature prevents ultraviolet light and water vapour from entering the nozzle when not in use. The shutter may comprise a plunger retained in the deposition chamber of the deposition head. Such a plunger means has a relative coaxial sliding fit with the nozzle whereby a plunger head aligns with the nozzl apertur to clos the nozzle and in an open position the plunger is retracted into the chamber. By controlling th position of the plunger head with respect to the nozzle aperture, the deposition chamb r size can be

controlled thereby allowing an adjustable droplet of deposition material to be ejected.

The nozzle may comprise means for directly varying the size of the nozzle aperture whereby the means is an iris type arrangement.

A deposition control electric field generator may be used to generate an electric field in the vicinity of the nozzle to control the shape of a meniscus of the electrically responsive deposit materials. This is used to exert a pulling force on the droplets so that less energy is required by the actuators to eject the droplets from the nozzle chamber.

Material may be dispensed in a vacuum to facilitate the deposition of droplets of diameter substantially less than or equal to 1μm. If this were attempted in air then the drag induced by air resistance would distort the droplet and impair its dimensional stability and placement accuracy.

Examples of electronic devices formed using the technique of droplet ejection will now be described with reference to Figures 4 to 7. The materials from which the various layers and regions of the devices are formed are given purely by way of example. The examples described with reference to Figures 4 to 6 do not fall within the scope of the present invention.

Figures 4a and 4b are cross-sections of a field effect transistor 200 formed on surface 202. The transistor 200 comprises gate region 204 formed from doped polyaniline, gate region insulator spacer 206 formed from one of polyimide, PMMA and siloxane, gate insulator 208 formed, depending on the gate characteristics, from one of polyimide and siloxane, source region 210 formed from doped polyaniline, drain region 212 also formed from doped polyaniline, and active semiconductor region 214 formed from pentacene, preferably doped pentacene. A protective acrylate-doped ormocer layer 216 may be formed over the surface of the transistor 200 to hermetically isolate the transistor 200.

The gate region insulator spacers 206 are shaped so as to control the electric field gradient E at the edges of the gate region 204 in order to minimise leakage current. The spacers 206 may take any desired shape, within the limits of droplet size and curing technique, that is, on the deposition technique

used.

In order to control the barrier height, an interface layer 218 is formed on the facing walls of the source region 210 and the drain region 212 prior to the deposition of the active semiconductor region 214, and into which the semiconductor region diffuses during deposition and/or curing thereof. The interface layer 218 may be formed from TCNQ or a liquid equivalent.

Figure 5 shows a cross-section of an example of a device for sensing hydrogen. The device comprises a chemotransistor 300, which comprises a substrate 302, preferably in the form of a flexible plastics sheet, polymeric insulator layers 304 and 306 formed from one of polyimide, PMMA and siloxane, source region 308 and drain region 310 formed from n-doped polyaniline, active semiconductor region 312 formed from p-doped polyaniline, source contact 314 formed from doped polyaniline, porous gate contact 316 formed from polyaniline doped with one of C_{60} or Cl, and drain contact 318 formed from doped polyaniline. All of the layers, regions and contacts 304 to 318 are formed by a droplet deposition technique.

Figure 6 shows a cross-section of a solar cell 400. The solar cell 400 is formed on a substrate 402, preferably a plastics sheet 402. A prelaminated aluminium layer 403 is pre-formed on the substrate 402. Alternatively, layer 403 may comprise a deposited layer of polyaniline with a layer of TCNQ for injecting electrons deposited thereon. A layer 404 of C_{60} doped PPV is deposited on layer 403, and a layer of intrinsic material 406, such as octaethylporphine, is deposited on the layer 404. Layer 408 of a p-type polymeric semiconductor material, such as OOPPV, and layer 410 of a transparent conductor, such as polyaniline, are subsequently deposited. An array of microlenslets 412, preferably formed from an ormocer, for maximising the light collection efficiency of the cell are then deposited on the layer 410.

Figure 7 shows a cross-section of a display pixel 500. The pixel is formed on a substrate 502, which may be either rigid or flexible. The pixel comprises a reflective base contact layer 504, which may be formed from aluminium. Upon layer 504 are deposit d isolation insulators 506, formed from one of polyimide, PMMA and siloxane, an active polymeric electroluminescent r gion 508 formed from a PPV derivative and a transparent ormocer top contact 510.

It will be understood that the present invention has been described above purely by way of example, and modifications of detail can be made within the scope of the invention.

CLAIMS

1. A method of forming at least part of an electronic display device using the technique of drop on demand printing to deposit droplets of deposition material, said method comprising depositing a plurality of droplets of fluid comprising soluble or dispersed phophor and/or dye on a selective area of a partially formed display device, and curing the deposited fluid by exposing the deposited fluid to electromagnetic radiation.

2. A method according to Claim 1, comprising the step of depositing one or more phosphor-containing layers adjacent to an imaging pixel of said partially formed display device.

3. A method according to Claim 1 or 2, wherein said imaging pixel is formed from one or more different deposition materials.

4. A method according to any preceding claim, wherein said fluid comprises a ferrous chelate.

5. A method according to any of Claims 1 to 3, wherein said fluid comprises a silicophosphate.

6. A method according to any of Claims 1 to 3, wherein said fluid comprises an ormocer.

7. A method according to any preceding claim, comprising selectively varying the deposition height over said selective area.

8. A method according to any preceding claim, wherein said display device comprises a flat panel display device.

9. A method according to any preceding claim, wherein said partially formed display device is formed on a rigid surface.

10. A method according to Claim 9, wherein said surface is formed from one of glass and plastics material.

11. A method according to any of Claims 1 to 8, wherein said partially formed display device is formed on a flexible surface.

12. A method according to Claim 11, wherein said surface is formed from plastics sheet material.

13. A method according to any preceding claim, further comprising the step of depositing an anti-reflection coating over said display device.

14. A method according to Claim 13, wherein said anti-reflection coating comprises one of scratch resistance, water permeation and dielectric isolation.